

Diffractive vector meson photoproduction at large t

Rikard Enberg, Leszek Motyka (Uppsala)
Gavin Poludniowski (Manchester)

DIS 2002, May 1, 2002

BFKL calculation of $\gamma p \rightarrow VX$ including all conformal spins n

Heavy vector mesons (J/ψ): extended to all n

Light vector mesons (ρ, ϕ): **new!**

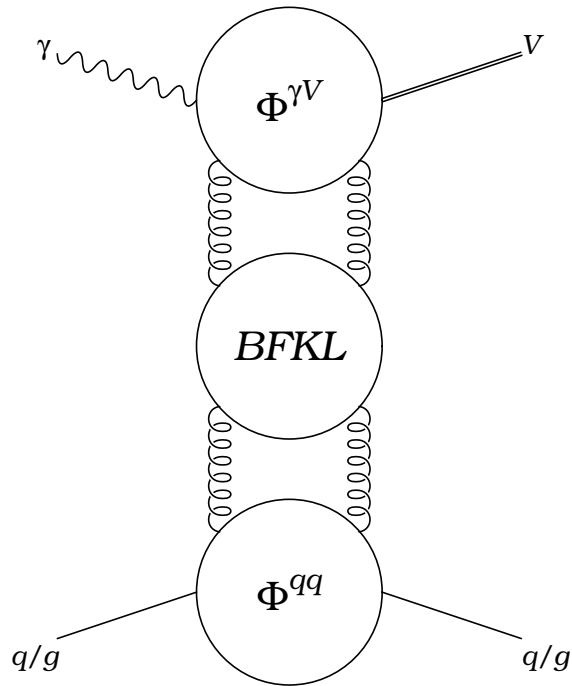
Results

Introduction

- High t VM production is a relatively clean observable – experimentally
- The large t may serve as a perturbative scale
 - test BFKL dynamics
- BFKL calculations done earlier in **conformal spin $n = 0$ approximation** (Forshaw-Ryskin, Bartels-Forshaw-Lotter-Wüsthoff, Forshaw-Poludniowski)
 - assuming delta function VM wave function
 - appropriate for **heavy** VM
 - no **helicity flip**
- Light vector mesons with helicity amplitudes: only done at Born level (Ivanov, Kirschner, Schäfer & Szymanowski)
 - introduce chiral-odd components of the photon wave function

The setup – BFKL calculation

Amplitude for scattering of two objects:



$$A \propto \int d^2\mathbf{k} d^2\mathbf{k}' f(\mathbf{k}, \mathbf{k}', y)$$

$$= \int d^2\mathbf{k} d^2\mathbf{k}' [\Phi^{q \rightarrow q} \otimes K_{\text{BFKL}} \otimes \Phi^{\gamma \rightarrow V}]$$

f satisfies the BFKL equation

The setup

Non-forward BFKL equation in LLA has solution due to Lipatov:

$$f \propto \sum_{n=-\infty}^{\infty} \int d\nu \frac{\nu^2 + \frac{n^2}{4}}{[\nu^2 + (\frac{n-1}{2})^2][\nu^2 + (\frac{n+1}{2})^2]} e^{\omega_n(\nu)y} I_{n,\nu}^1(\mathbf{k}, \mathbf{q}) I_{n,\nu}^{2*}(\mathbf{k}', \mathbf{q})$$

$\omega_n(\nu)$ = eigenvalues of the BFKL kernel

$I_{n,\nu}^{1,2}$ = projections of $\Phi^{1,2}(\mathbf{k}, \mathbf{q})$ on the BFKL conformal eigenfunctions $E_{n,\nu}$

Quark-quark impact factor:

$$\Phi^{q \rightarrow q} = \alpha_s \sim \text{constant} \Rightarrow I_{n,\nu}^{q \rightarrow q} \propto \delta\text{-functions}$$

\Rightarrow we use Mueller-Tang prescription generalized to arbitrary n

(Motyka, Martin, Ryskin PLB 524, 107)

Conformal spin

The conformal spin n is an integer labelling the eigenfunctions.

- $\omega_n(\nu) < 0$, but for $|n| > 0$, $e^{\omega_n(\nu)y} \ll e^{\omega_0(\nu)y}$

⇒ expect strong suppression of $n \neq 0$ terms with increasing y

⇒ **amplitude usually approximated by $n = 0$ component**

- However. . .

- **y is usually not large enough in present day experiments!**

- Gaps between jets: higher n needed to reproduce data

Enberg,Ingelman,Motyka [PLB 524,273] & Motyka,Martin,Ryskin [PLB 524,107]

⇒ Gives different behaviour in y and q for moderate rapidities

The $\gamma \rightarrow J/\psi$ impact factor

Non-relativistic approximation

- no longitudinal d.o.f., meson wave function $\sim \delta(u - 1/2)$
 $u =$ longitudinal momentum fraction of quark
- $M_V \approx 2m_q$
- The impact factor is

$$\Phi^{\gamma \rightarrow V}(\mathbf{k}, \mathbf{q}) = 2\mathcal{C}\alpha_s \left(\frac{1}{Q^2 + M_V^2 + q^2} - \frac{1}{Q^2 + M_V^2 + 4k^2} \right)$$

The result for even n is (odd n gives 0)

$$\begin{aligned}
 I_{n,\nu}^{\gamma \rightarrow V}(q) &= \mathcal{C} \alpha_s \frac{8\pi^2}{|q|^3} \left(\frac{|q|^2}{4}\right)^{i\nu} \left(\frac{\bar{q}}{q}\right)^{n/2} \left(\frac{1}{4}\right)^{|n|/2} \frac{\Gamma(1/2 - i\nu + |n|/2)}{\Gamma(1/2 + i\nu + |n|/2)} \\
 &\times \int_{-i\infty}^{i\infty} \frac{ds}{2\pi i} \tau^{1/2+s+|n|/2} \frac{\Gamma(1-s-i\nu) \Gamma(1-s+i\nu)}{\Gamma(1-s/2-i\nu/2) \Gamma(1-s/2+i\nu/2)} \\
 &\times \frac{\Gamma^2(1/2+s+|n|/2)}{\Gamma(1/2+s/2-i\nu/2+|n|/2) \Gamma(1/2+s/2+i\nu/2+|n|/2)}
 \end{aligned}$$

which represents a generalization of an earlier result for $n = 0$ by

Bartels, Forshaw, Lotter and Wüsthoff [PLB 375, 201]

The $\gamma \rightarrow \rho$ impact factor

Ivanov, Kirschner, Schäfer & Szymanowski [PLB 478 (2000)] give the 2-gluon exchange helicity amplitudes $M_{(++)}$, $M_{(+-)}$ and $M_{(+0)}$ for vector mesons.

- relativistic calculation, assumes massless quarks
- longitudinal (u) and transverse (r) d.o.f. factorized

\Rightarrow more complicated impact factors!

For instance:

$$M_{+0} = C \alpha_s^2 \int \frac{d^2 \mathbf{k}}{\mathbf{k}^2 (\mathbf{k} - \mathbf{q})^2} \underbrace{\frac{d^2 \mathbf{r} du}{4\pi} f^{\text{dipole}} \frac{\mathbf{r} \cdot \mathbf{e}^+}{r^2} \frac{f_\rho}{2} (1 - 2u) \phi_{\parallel}(u)}_{\sim \Phi^{q \rightarrow q}(\mathbf{k}', \mathbf{q}) \times \Phi_{(+ -)}^{\gamma \rightarrow V}(\mathbf{k}, \mathbf{q}) \times \delta(\mathbf{k} - \mathbf{k}')}$$

- $f^{\text{dipole}} = e^{i \mathbf{q} \cdot \mathbf{r} u} (1 - e^{-i \mathbf{k} \cdot \mathbf{r}}) (1 - e^{-i (\mathbf{q} - \mathbf{k}) \cdot \mathbf{r}})$
- $\phi_{\parallel}(u)$ is the twist-2 vector meson wave function

\Rightarrow We pick the $\Phi_{(hel.)}^{\gamma \rightarrow V}$ from IKSS!

The result

The impact factor $I_{n,\nu}^{\gamma \rightarrow V}$ is proportional to the integral ($\mu = \frac{n}{2} - i\nu$)

$$\mathcal{I} \propto \left[\sin \pi \left(\frac{1}{2} + \beta + \tilde{\mu} \right) B_+(\alpha, \bar{k}, \bar{q}) \tilde{B}_+(\beta, k, q) \right. \\ \left. - (-1)^n \sin \pi \left(\frac{1}{2} + \beta - \tilde{\mu} \right) B_-(\alpha, \bar{k}, \bar{q}) \tilde{B}_-(\beta, k, q) \right]$$

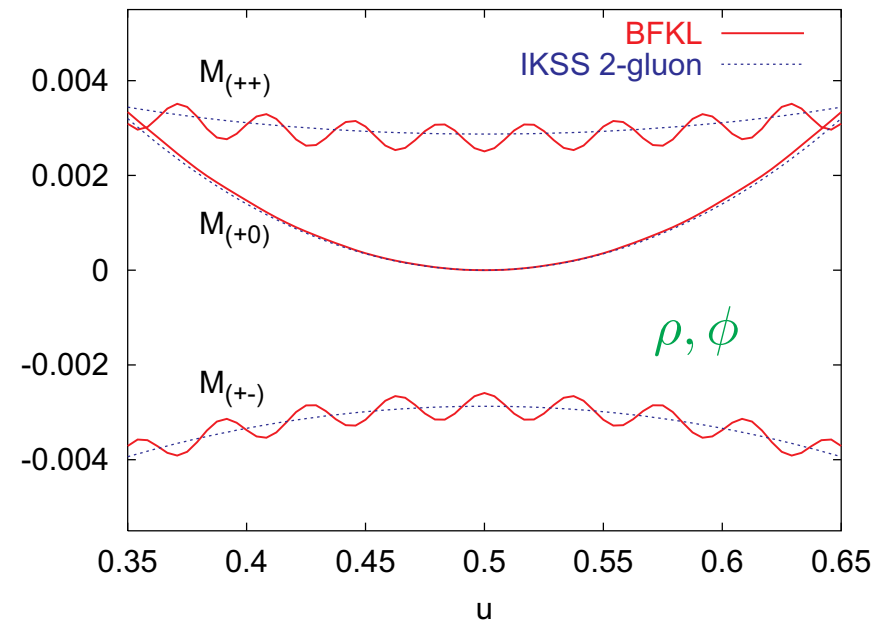
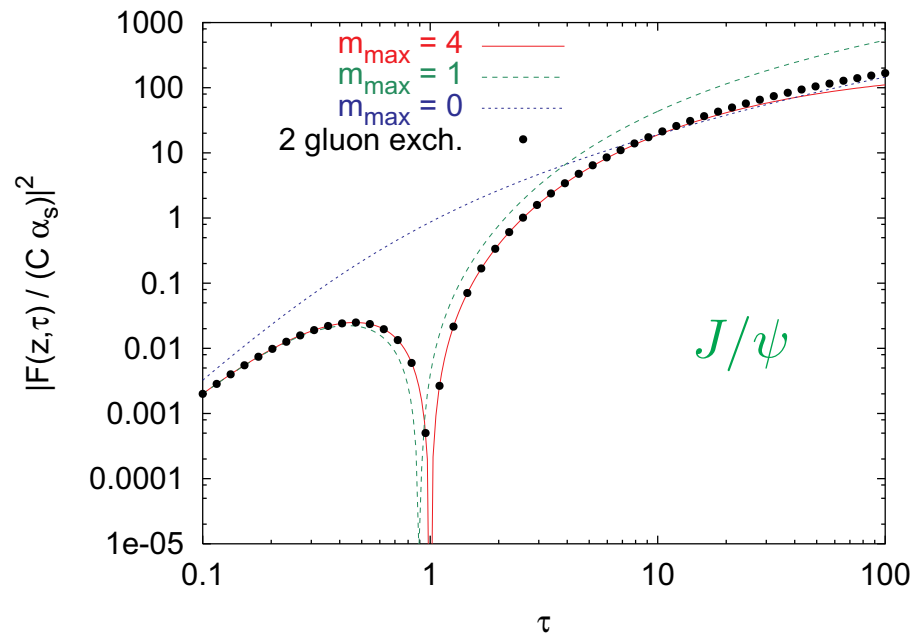
where we introduce **conformal blocks** B :

$$B_{\pm}(\alpha, k, q) = \left(\frac{2i}{k} \right)^{\frac{3}{2} + \alpha} \left(\frac{iq}{4k} \right)^{\pm \mu} \frac{\Gamma(\frac{3}{2} + \alpha \pm \mu)}{\Gamma(1 \pm \mu)} \\ \times {}_2F_1 \left(\frac{3}{2} + \alpha \pm \mu, \frac{1}{2} \pm \mu; 1 \pm 2\mu; \frac{\bar{q}}{\bar{k}} \right)$$

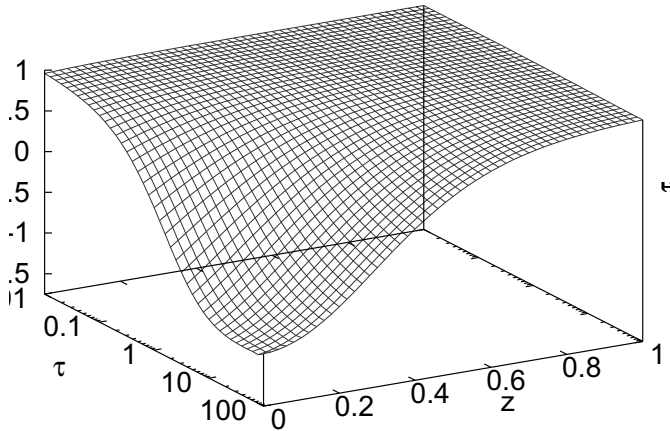
which is similar to an earlier result by Navelet & Peschanski [NPB 507 353] concerning dipole-dipole amplitudes

Important crosscheck:

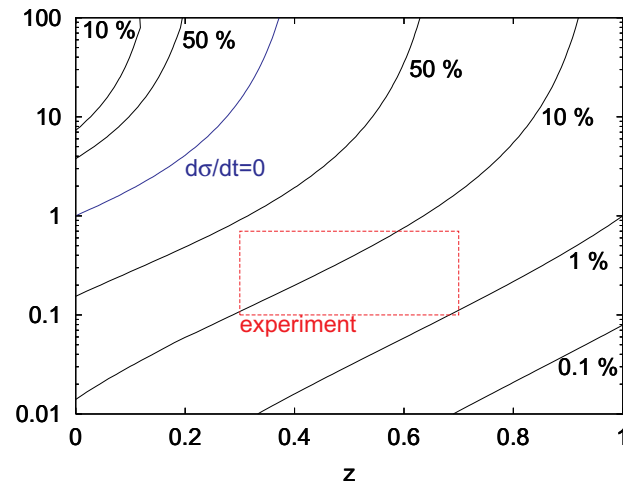
The BFKL amplitude at $y = 0$ has no evolution
 \Rightarrow it must reproduce the Born-level (2-gluon) calculation



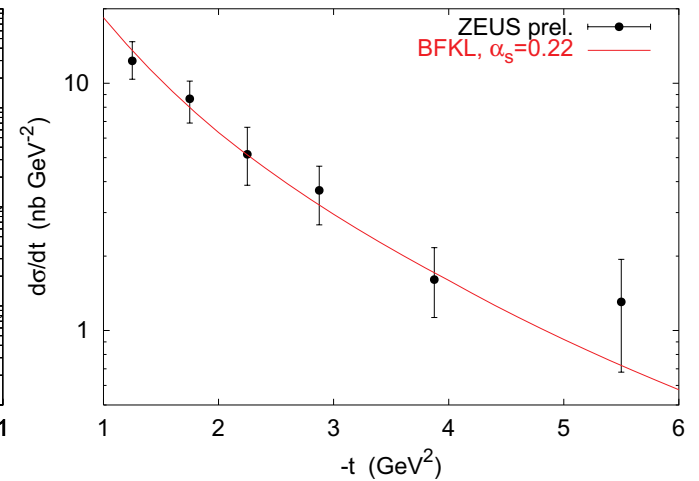
J/ψ results – influence of higher n



$$A_{exact}/A_0$$



$$\mathcal{E} = \frac{|A_{exact}|^2 - |A_0|^2}{|A_0|^2}$$



$$\frac{d\sigma}{dt}$$

(Here $\tau = \frac{|t|}{M_V^2 + Q^2}$, $z = \frac{3\alpha_s}{2\pi} y$, $y = \text{rapidity}$)

For J/ψ : influence of higher conformal spins not so large at present experiments!

ρ results – a first look:

Helicity density matrix elements
measured by ZEUS

$$\alpha_s = 0.24 \Rightarrow \omega_0 = 0.64 \text{ in kernel}$$

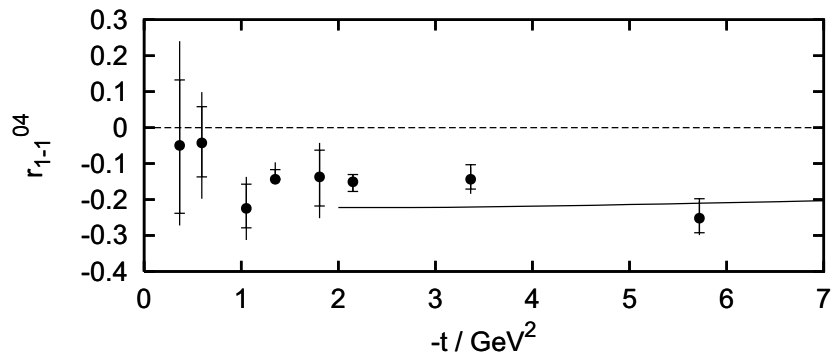
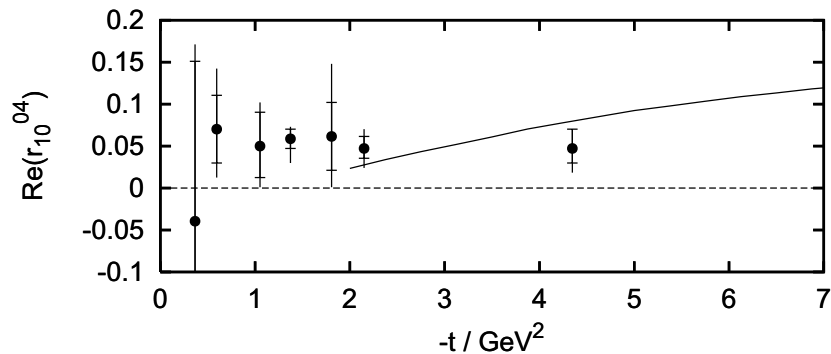
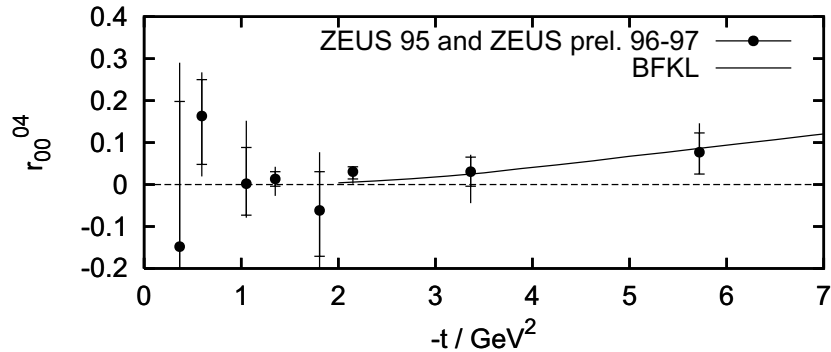
$$\alpha_s = 0.38 \text{ in prefactor}$$

Rapidity defined as $y = \ln \frac{\hat{s}}{M_V^2}$

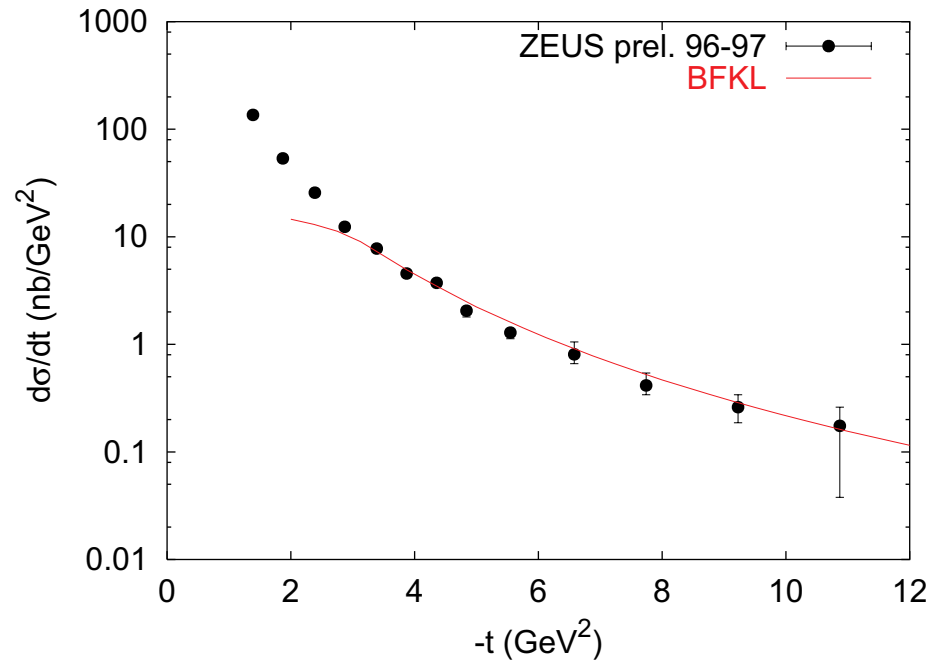
→ Many conformal spins needed in sum!

→ Spin double-flip amplitude dominates

→ No-flip amplitude changes sign
through BFKL evolution



ρ results – the cross section



Reproduces $d\sigma/dt$ with
chosen parameters

→ Not reliable for small $|t|$
(pQCD not valid)

→ also because of cut-off in
 u integration: $u_{\min} = -t/M_{\rho}^2$
which is too restrictive

Further analysis is on the way!

Discussion

- Very **different interpretation** of helicity amplitudes than the Born-level calculation (IKSS) using chiral-odd photon wave functions
- Intermediate t region:
 - In our case, **$(+-)$ dominates and $(++)$ changes sign**
 - for IKSS, **$(++)$ dominates and $(+-)$ has different sign**
- **$(+-)$ dominates for small $M_V \longrightarrow (++)$ dominates for large M_V — how?**
- Assumptions:
 - massless quarks
 - wave function factorization — valid for large r ?
→ **Further investigation needed**

Conclusions

- We have obtained exact LL BFKL formulae for the $\gamma q \rightarrow Vq$ amplitude
→ helicity amplitudes for light vector mesons
- Numerical evaluation → experimental data is reproduced
- In particular, the general helicity structure can be reproduced
- Different picture than Born-level with chiral-odd components